RHODORA, Vol. 105, No. 922, pp. 153–177, 2003

THE VASCULAR FLORA OF MUD POND PEATLAND, CARROLL COUNTY, NEW HAMPSHIRE

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ABSTRACT. Mud Pond peatland (Moultonborough, New Hampshire) is an approximately 12 ha wetland with a flora that consists of 124 vascular plant species, representing 46 families. Among the flora of Mud Pond peatland were two New Hampshire Endangered species (*Arethusa bulbosa* and *Carex diandra*), one New Hampshire Threatened species (*Lysimachia thrysiflora*), and four New Hampshire Species of Special Concern (*Calopogon tuberosus*, *Platanthera blephariglottis*, *Pogonia ophioglossoides*, and *Sarracenia purpurea*). During field reconnaissance, the vegetation of Mud Pond peatland was qualitatively classified as follows: *Nuphar variegata–Nymphaea odorata* (aquatic), *Carex lasiocarpa* (sedge fringe), *Vaccinium oxycoccos–Sarracenia purpurea* (*Sphagnum* lawn), *Picea mariana–Carex trisperma* (muskeg), *Chamaedaphne calyculata* (ericaceous scrub), *Typha latifolia–Carex lacustris* (marsh), and *Nemopanthus mucronatus–Calamagrostis canadensis* (lagg) communities. Based primarily on vegetation and basin characteristics, Mud Pond peatland can tentatively be classified as a *Sphagnum*-dominated poor fen.

Key Words: New Hampshire, Carroll County, flora, peatland, vegetation

Peatlands are wetland ecosystems characterized by the prolific deposition of organic peat (Vitt 2000). In northeastern North America, peat typically contains no less than 20% partially decayed organic matter (McQueen 1990). These organic substrates are predominantly the remains of *Sphagnum* mosses, sedges, and ericaceous shrubs (Crum 1988; Moore and Bellamy 1974; Vitt 2000). The interaction of physical (e.g., pH, nutrient levels, anoxia) and biological parameters, especially the dominance of *Sphagnum* mosses, perpetuate the deposition and accumulation of peat in these unique wetlands (Clymo and Hayward 1982; Crum 1988; Gorham 1957; Johnson 1985; McQueen 1990; van Breeman 1995; Vitt 2000).

Vegetation in peatlands is distributed along gradients of minerotrophy, pH, moisture, and light (e.g., Crum 1988; Damman and French 1987; Gignac and Vitt 1994; Gorham and Janssens 1992; McQueen 1990; Vitt and Slack 1975). Certain areas within a peatland such as a pond shoreline, the lagg bordering the upland, or networks of sunken

hollows, typically have vegetation with minerotrophic affinities. Conversely, partially elevated areas on grounded mats, such as large *Sphagnum* hummocks, may be colonized by groups of species associated with comparatively oligotrophic to ombrotrophic microhabitat conditions (Crum 1988; Damman and French 1987; Glaser 1987; McQueen 1990; Schwintzer 1978; Vitt et al. 1975, 1995).

Regionally, peatlands tend to be colonized by both bryophyte and vascular taxa that are highly predictable from site to site (Gore 1983; Johnson 1985; Vitt 2000; Waterman 1926; Wheeler et al. 1983). In northern latitudes such as New England and the upper Midwest of North America, peatlands typically have a distinct boreal physiognomy characterized by *Picea* spp. and ericaceous shrubs compared to other wetlands such as swamps or marshes (Crum 1988; McQueen 1990). Peatlands provide cool, nutrient-poor habitats where species at the southern extent of their geographic range may occur (Andreas and Bryan 1990; Andreas and Host 1983; Braun 1928, Damman and French 1987; Sperduto 1997). Despite the large volume of literature on peatland ecology, there is a relatively limited number of studies that have examined peatland ecology in New England (e.g., Anderson and Davis 1997; Bubier 1991; Damman and French 1987; Dunlop 1987; Fahey and Crow 1995; Mitchell and Niering 1993; Moizuk and Livingston 1966; Motzkin and Patterson 1991; Searcy and Hickler 1999; Worley 1981).

Although studies are relatively scarce, New Hampshire peatlands have been used as sites for a variety of research ranging from assessments of peat quality to paleoecological and biogeochemical studies (e.g., Davis et al. 1980; Frolking and Crill 1994; Krauss and Kent 1944; Murray 1994; White 1941). One of the first examinations of the vegetation of a New Hampshire peatland was a description of the flora and vegetation patterns of Rochester Heath Bog (Rochester, Strafford County; Barrett 1966). Dunlop (1983, 1987) described the flora and vegetation of Mud Pond Bog (Hillsborough, Hillsborough County) while similar studies were conducted at Pequawket and Heath Pond Bogs (Ossipee, Carroll County) by Fahey (1993) and Fahey and Crow (1995). The bryophyte and vascular vegetation of Spruce Hole Bog (Durham, Strafford County) as well as the dendrochronology of conifers within the kettlehole was examined by Miller (1996).

This floristic inventory of Mud Pond peatland augments the literature describing the vegetation of New Hampshire's peatlands. The purpose of this study was to compile a vascular species inventory of the flora of Mud Pond peatland documented by herbarium voucher specimens. This

study also describes the major plant communities within Mud Pond peatland in relation to other New Hampshire peatlands.

SITE DESCRIPTION

Mud Pond peatland (elevation 165 m) is located in Moultonborough, New Hampshire about 5 km west of Moultonborough Village (Carroll County), and approximately 3 km east of Center Harbor (43°43′22″N, 71°25′37″W). The approximately 12 ha peatland is located just north of Moultonborough Neck at the northern end of Lake Winnipesaukee. Mud Pond is located in the center of the peatland and has an inlet/outlet stream (Mud Pond Brook) that runs roughly from north to south through the basin (Figure 1).

The peatland is located within the Southern New England Coastal Plain and Hills Section (Sebago-Ossipee Hills and Plain subsection) according to the classification of the natural divisions of New Hampshire (Smith 1996). This region is known for its mountainous topography, glacial features, and its extensive lakes and wetlands. The forests of the surrounding upland belong to the "Hemlock–White Pine–Northern Hardwoods Region," and consists of both deciduous, coniferous, and mixed forest stands (Braun 1950). The peatland basin is situated among development that includes homes, businesses, recreation fields, and town highway department facilities.

Part of the 6 ha tract of land adjacent to the peatland where the recreation area now exists was donated to Moultonborough in 1974. This area was once the site of a gravel pit as well as the Moultonborough town garage (Anonymous 1974). The recreation facility was constructed during the late 1970s and apparently claimed parts of the western end of the peatland. The 1974 Annual Report of the Town of Moultonborough noted that the project would be completed over a two-year period and refered to earth moving and "ground drainage" at the site of the recreation area (Anonymous 1974). The 1975 Annual Report of the Town of Moultonborough noted the procurement of dredge and fill permits for the recreation area project (Anonymous 1975).

Climate. Carroll County has a climate characterized by moderate summer temperatures, cold winters, and substantial precipitation throughout the year (Diers and Vieira 1977). There is typically 107 cm of annual precipitation in the Lake Winnipesaukee vicinity and approximately 117 cm at Conway. The mean snowfall within Carroll County ranges from 191–318 cm. Snow cover lasts from early December through April. January is the coldest month of the year with average temperatures

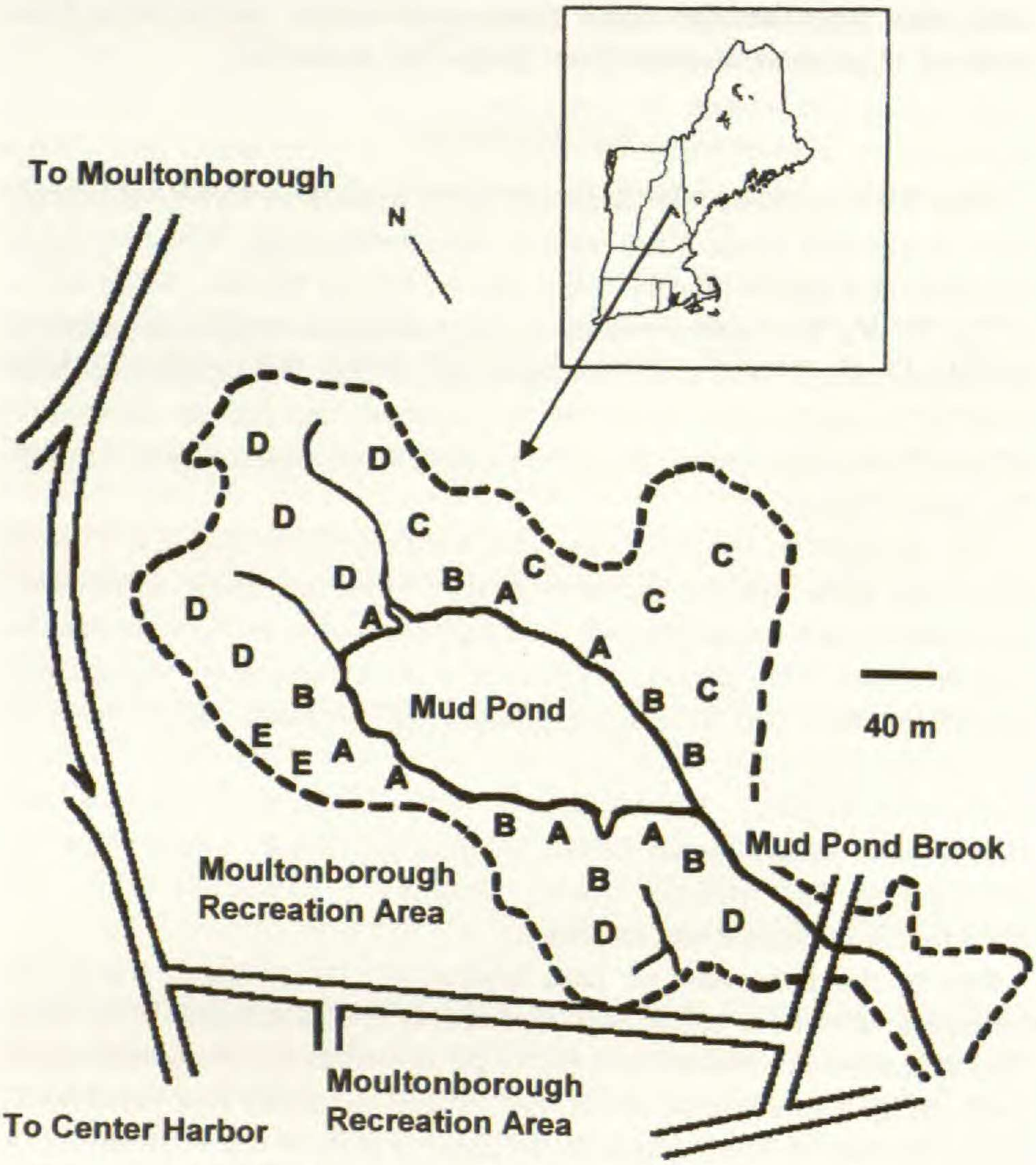

Figure 1. Map of Mud Pond peatland and surroundings. Letters indicate approximate position of selected communities. The sedge fringe and lagg communities are not noted due to their predominance along the pond shore and upland perimeter of the peatland respectively. A. *Vaccinium oxycoccos–Sarracenia purpurea* community; B. *Picea mariana–Carex trisperma* community; C. *Chamaedaphne calyculata* community; D. *Typha latifolia–Carex lacustris* community; E. Open water within the *Nemopanthus mucronatus–Calamagrostis canadensis* community. Redrawn and modified from the Town of Moultonborough Property Map by John E. O'Donnell and Associates, Auburn, ME (1973).

approximately –7°C to –5°C. July is the warmest month of the year with average temperatures approximately 15–21°C.

Soils and geology. The topography of Carroll County has been influenced by the effects of the last glaciation that receded from the area

approximately 14,000 years ago (Diers and Vierra 1977). The uplands around Mud Pond peatland consist mainly of glacial tills that belong to the Hollis-Gloucester-Charlton association. These well-drained soils of sand and loam have formed at various depths over bedrock on uplands and mountains. The soils of the peatland basin are classified as "Freshwater Marsh." These soils are immersed most of the year, frost prone, and are colonized by graminoid vegetation including cattails and rushes.

The underlying bedrock of Mud Pond peatland consists of Winnipesaukee Quartz diorite, a medium-grained igneous rock composed of gray quartz and diorite. Red Hill is located immediately north of Mud Pond peatland and is characterized by alkaline geology that is an unusual feature in New Hampshire (Billings 1955; Quinn 1937).

MATERIALS AND METHODS

From May through October of 1993, a floristic inventory of the vascular vegetation of Mud Pond peatland was compiled. From June through August the peatland was surveyed at least once a week. A survey consisted of several hours in the field and at least a single circumnavigation of the peatland to ensure that the basin was consistently observed throughout the entire growing season. Botanical reconnaissance was conducted on foot and by canoe. All plant species growing on organic soils (including beaver lodges) within the topographical limits of the peatland were included in the flora. The abundance of each species was estimated using a visual abundance index (described in the Appendix). Plant communities within the peatland were described based on visual prominence of constituent species. Vascular plant communities were named according to prominent taxa and were given a synonymous habitat designation based on the physiognomy of the community.

Voucher specimens were collected and deposited at the Hodgdon Herbarium at the University of New Hampshire, Durham (NHA). Nomenclature follows Gleason and Cronquist (1991) and Crow and Hellquist (2000a, b) except for the pteridophytes, gymnosperms, and members of the Magnoliidae and Hamamelidae which follow Flora of North America Editorial Committee (1993, 1997).

RESULTS

In 1993, the vascular flora of Mud Pond peatland consisted of 124 species, representing 46 families and 83 genera (Appendix). During the floristic inventory, seven plant communities were described based on

qualitative field observations. These vegetation types were visually distinct, although in many areas one community blended gradually into neighboring communities. The three most abundant vascular plant families in the peatland were the Cyperaceae (22 species), the Ericaceae (11 species), and the Rosaceae (8 species). The species within these three families represented 33% of the peatland flora. Four non-native species (*Lythrum salicaria*, *Solanum dulcamara*, *Trifolium repens*, and *Verbascum thapsus*) grew within the basin and consisted of 3.0% of the species richness of the flora. *Arethusa bulbosa* and *Carex diandra* have "endangered" status for the state of New Hampshire and *Lysimachia thrysiflora* has "threatened" status for the state (DRED 2000).

Seven plant communities (with habitat designation in parentheses) were described. These communities were the *Nuphar variegata–Nymphaea odorata* (aquatic), *Carex lasiocarpa* (sedge fringe), *Vaccinium oxycoccos–Sarracenia purpurea* (*Sphagnum* lawn), *Picea mariana–Carex trisperma* (muskeg), *Chamaedaphne calyculata* (ericaceous scrub), *Typha latifolia–Carex lacustris* (marsh), and *Nemopanthus mucronatus–Calamagrostis canadensis* (lagg) communities.

DISCUSSION

Vegetation of Mud Pond peatland. During the floristic inventory of Mud Pond peatland, vegetation patterns within the peatland became apparent. The approximate locations and characteristics (Figure 1) of the seven communities are summarized with particular emphasis on prominent plant species. These communities are described based on field observations without quantitative sampling. General comparisons of the vegetation patterns at Mud Pond to other New Hampshire peatlands are emphasized. For the purposes of clarity, Mud Pond Bog in Hillsborough, New Hampshire described by Dunlop (1983, 1987), is referred to as "Hillsborough Bog."

1. *Nuphar variegata–Nymphaea odorata* (aquatic) Community

Submersed and floating aquatic species grew within the open water of Mud Pond, the various streamlets that dissect portions of the peatland mat, Mud Pond Brook, and portions of the lagg that contain open water (Figure 1). Mud Pond has a false bottom of peat and organic detritus that is especially prominent around the perimeter of the pond. Anchored in the false bottom were aquatic macrophytes including *Nuphar variegata*, *Nymphaea odorata*, *Potamogeton amplifolius*, *P. natans*, and *Utricularia vulgaris*.

At Hillsborough Bog the aquatic community was dominated by *Nymphaea odorata* (33% coverage) and *Brasenia schreberi* J. F. Gmel. (26%), with *Nuphar variegata* and *Pontederia cordata* also prominent in some areas (Dunlop 1987). A similar, but more diverse aquatic community at Pequawket Bog was characterized by *N. odorata*, *Utricularia purpurea* Walter, and *Eleocharis robbinsii* Oakes (Fahey and Crow 1995). *Nuphar variegata*, *Potamogeton confervoides* Rchb., and *U. intermedia* were also present at Pequawket Bog. Spruce Hole Bog contained only one aquatic species, *U. geminiscapa* Benj. (Miller 1996).

2. *Carex lasiocarpa* (sedge fringe) Community

Carex lasiocarpa formed the immediate margin along the entire shore of Mud Pond. This fringe also extended to varying degrees along Mud Pond Brook where it blended with the marsh communities in northern and southern areas of the wetland. The dominance of *C. lasiocarpa* has been considered by many researchers to reflect more minerotrophic (fen-like) conditions (Crum 1988; Schwintzer 1978; Vitt and Slack 1975; Wheeler et al. 1983). Other prominent species in the sedge fringe included *Chamaedaphne calyculata*, *Cladium mariscoides*, *Myrica gale*, *Peltandra virginica*, *Triadenum virginicum*, and *Alnus incana*. The sedge fringe was also the primary habitat of *Arethusa bulbosa*. Another orchid, *Platanthera blephariglottis*, was an occasional inhabitant of the transitional area between the *C. lasiocarpa* and *Vaccinium oxycoccos–Sarracenia purpurea* communities.

A similar community was described at Pequawket Bog (Fahey and Crow 1995). At Pequawket Bog, *Carex lasiocarpa* was a dominant component of the shoreline vegetation as were *Chamaedaphne calyculata*, *Myrica gale*, and *Vaccinium macrocarpon*. Other frequently observed species in this cover type included *Peltandra virginica*, *Pogonia ophioglossoides*, *Sagittaria latifolia*, and *Triadenum virginicum*. This same suite of species also was prevalent in the *C. lasiocarpa* community at Mud Pond. No analogous community was recorded at Rochester Heath Bog (Barrett 1966), Hillsborough Bog (Dunlop 1987), Heath Pond Bog (Fahey 1993), or Spruce Hole Bog (Miller 1996).

3. *Vaccinium oxycoccos–Sarracenia purpurea* (*Sphagnum* lawn) Community

Areas of the *Vaccinium oxycoccos–Sarracenia purpurea* community were located adjacent to the *Carex lasiocarpa* community (Figure 1). These lawns are small-scale poor fens defined by an open, floating, saturated surface of *Sphagnum* species (Crum 1988). These areas were

encroached upon by the *Picea mariana–C. trisperma* community and *Chamaedaphne calyculata* community in the western, southwestern, and northeastern areas of the peatland. In the northwestern and south-southeastern portions of the peatland the *Typha latifolia–Carex lacustris* community abutted *Sphagnum* lawn habitats. The *Sphagnum* lawn and sedge fringe formed the characteristic quaking mat associated with pond-border peatlands. Instead of forming extensive broad mats, these *Sphagnum* lawns were confined to pockets between neighboring communities.

Although not expansive, the *Sphagnum* lawns at Mud Pond peatland were inhabited by numerous vascular plants. *Vaccinium oxycoccos* was abundant, as were stunted individuals of *Chamaedaphne calyculata* and *Andromeda glaucophylla*. Insectivorous species such as *Sarracenia purpurea* and *Drosera rotundifolia* were also prominent. *Drosera intermedia* was uncommon and found in trough-like hollows where standing water pooled. *Calopogon tuberosus* also thrived in the open conditions of this community.

At Pequawket Bog, a similar community was characterized by a quaking mat of low *Chamaedaphne calyculata* with *Vaccinium oxycoccos* and *Eriophorum virginicum* (Fahey and Crow 1995). Dunlop (1983, 1987) designated an analagous community at Hillsborough Bog as the "*Vaccinium oxycoccos–Rhynchospora alba* subtype" of the "*C. calyculata* cover type." At Spruce Hole, the "*Sphagnum*–Sedge Lawn community" was described based on the dominance of *S. recurvum* P. Beauv., dwarf ericaceous shrubs including *C. calyculata*, *Lyonia ligustrina*, and *V. corymbosum*. Sedge species of this community included *Carex canescens*, *Eriophorum tenellum*, and *E. virginicum* (Miller 1996).

4. *Picea mariana–Carex trisperma* (muskeg) Community

A muskeg is an area of peatland dominated by *Sphagnum*, *Picea mariana*, *Larix laricina*, and ericaceous species (Heinselman 1963). Muskeg vegetation is often associated with older areas of grounded mat (Crum 1988). At Mud Pond, the most extensive areas of muskeg were at the northeast, east, and southwest ends of the peatland, with smaller pockets of *P. mariana* occurring sporadically throughout the basin. The *P. mariana–Carex trisperma* community formed stands of partially closed canopies that usually were located adjacent to the *Vaccinium oxycoccos–Sarracenia purpurea* and *Chamaedaphne calyculata* communities.

Among the stands of *Picea mariana* the flora was depauperate. The dominant herb was *Carex trisperma*, which formed an uneven carpet

of hummocks from which woody species such as *Alnus incana*, *Chamaedaphne calyculata*, *Gaylussacia baccata*, *Kalmia polifolia*, and *Vaccinium myrtilloides* grew. In shallow, damper areas between hummocks, *Peltandra virginica* and *V. macrocarpon* were sometimes observed. Damman and French (1987) recognized a similar community, the "*Sphagnum magellanicum–P. mariana* forest" that is characterized by sparse to abundant individuals of *P. mariana* with an understory of ericaceous shrubs that dwindles as overstory shading increases.

In the northeastern and southwestern areas of the peatland, the muskeg community expanded into an open *Picea mariana* parkland characterized by hummock-hollow microtopography. This hummock-hollow complex eventually graded into the *Chamaedaphne calyculata* and *Typha latifolia–Carex lacustris* communities. The hummocks were dominated by *Sphagnum* species, *Eriophorum vaginatum*, and a dense turf of *C. trisperma*. Sunken hollows formed a network around the hummocks. In these saturated hollows, species such as *Calopogon tuberosus*, *Drosera rotundifolia*, *E. virginicum*, *Platanthera blephariglottis*, *Rhynchospora alba*, *Sarracenia purpurea*, and *Vaccinium oxycoccos* were abundant.

A dense population of *Picea mariana* was located at Spruce Hole Bog (Miller 1996). Due to the lack of penetrating light, there was scant ground cover in this community. The understory consisted primarily of *Carex trisperma* and *Gaultheria hispidula* (L.) Muhl. *ex* Bigelow. Despite the relative lack of vascular species richness in the understory of the *P. mariana* stands at Spruce Hole Bog, there were twelve species of bryophytes present including four *Dicranum* species, three *Sphagnum* species, and three "leafy" liverwort species. The *Dicranum* and liverwort species were limited to the *P. mariana* understory. Closed canopies of *P. mariana* were absent at Pequawket, Heath Pond, and Hillsborough peatlands (Dunlop 1987; Fahey 1993; Fahey and Crow 1995). Heath Pond Bog has an extensive open muskeg similar to areas on the southwestern side of Mud Pond (Fahey 1993; Hellquist, pers. obs.). Similar *P. mariana* communities are abundant in peatlands in upper Michigan (Vitt and Slack 1975).

At Mud Pond, the muskeg communities were impacted by beavers. In the late spring of 1993, a single beaver lodge approximately 7.0 m long, 4.5 m wide, and about 2.0 m high, existed on the northwestern edge of the peatland. By early summer, beavers had excavated a channel into a stand of *Picea mariana* at the southwestern end of the peatland and constructed a second lodge composed of mud, branches, and small trunks of *P. mariana*. Beaver activity was evident at the mouth of Mud

Pond Brook and in muskeg areas along the entire western end of the peatland. Similar harvests of *P. mariana* by beavers at Beckley Bog (Norfolk, Connecticut) have been noted by Mitchell and Niering (1993).

The presence of beaver lodges on the peatland mat was also interesting botanically. On the muddy, elevated beaver lodges grew a variety of plant species not usually associated with peatland floras. Some of these unexpected, opportunistic species restricted to beaver lodges included *Erechtites hieraciifolia*, *Fragaria virginiana*, *Impatiens capensis*, *Polygonum arifolium*, and *Verbascum thapsus*.

5. *Chamaedaphne calyculata* (ericaceous scrub) Community

The ericaceous scrub and the muskeg were found on the grounded mat of the peatland and formed the most internal communities of the peatland. The ericaceous scrub community was limited to the east and southeast areas of the basin and consisted of the most homogeneous vegetation within the peatland. This community was characterized by broad expanses of *Andromeda glaucophylla*, *Chamaedaphne calyculata*, *Kalmia angustifolia*, and *K. polifolia* growing among hummocks of *Sphagnum*.

Animal trails provided habitat for other species including *Eriophorum virginicum*, *Peltandra virginica*, and occasionally *Calla palustris* within the scrub. Another microhabitat found in the ericaceous scrub was located in areas where trees including *Larix laricina*, *Picea mariana*, or *Pinus strobus* had died, leaving large, uplifted, circular hummocks a few meters in diameter. These elevated areas provided habitat for species such as *Kalmia angustifolia*, *Rhododendron canadense*, *Vaccinium corymbosum*, and *V. myrtilloides* as well as saplings of *Acer rubrum*, *L. laricina*, and *P. strobus*.

Ericaceous scrub-dominated communities are present at Rochester Heath Bog (Barrett 1966), Hillsborough (Dunlop 1987), Heath Pond (Fahey 1993), Pequawket (Fahey and Crow 1995), and Spruce Hole (Miller 1996) bogs. In all of these peatlands, *Sphagnum* carpeted the substrate. Often sedges such as *Carex trisperma*, *Eriophorum vaginatum*, *E. virginicum*, and *Rhynchospora alba* were interspersed within the ericaceous shrubs (Dunlop 1987; Fahey and Crow 1995). Similar vegetation communities dominated by ericaceous shrubs have been documented across the Northeast (Anderson and Davis 1997; Damman and French 1987; Johnson 1985; Worley 1981) and in the Midwest (Crow 1969; Crum 1988; Gates 1942; Hellquist and Crow 1999; Schwintzer 1981; Vitt and Slack 1975).

6. *Typha latifolia–Carex lacustris* (marsh) Community

The marsh community of Mud Pond peatland was characterized by standing and moving channels of water that were surrounded by *Typha latifolia* and graminoid species. The largest expanse of the marsh occurred at the northern end of the peatland where it surrounded the inlet stream to Mud Pond. A second substantial area of marsh occurred at the southeastern end of the peatland along Mud Pond Brook (Figure 1). The southeastern marsh extends to the west behind the muskeg where it encompasses another stream that drains into a culvert across from the recreation area hockey rink.

The northern marsh area was distinguished by tussocks of *Carex stricta* that were often surrounded by water. *Utricularia intermedia* was abundant in the narrow channels of water around these tussocks. At the northern inlet to Mud Pond, the extensive expanse of *Carex* tussocks and *Typha latifolia* formed a network of channels with false bottoms. The marsh areas also were colonized by *C. lacustris*, *C. lasiocarpa*, and *C. pseudocyperus*. This vegetation is associated with moving water as well as with fen and marsh habitats (Crum 1988). Farther from the inlet, the tussock complexes contained abundant *T. latifolia* as well as *Acer rubrum* (seedlings and saplings), *Osmunda cinnamomea*, *O. regalis*, *Thelypteris palustris*, *Alnus incana*, *Calamagrostis canadensis*, *Chamaedaphne calyculata*, *Spiraea latifolia*, *Toxicodendron vernix*, *Triadenum virginicum*, and *Vaccinium macrocarpon*.

The marsh in the southwestern portion of the peatland basin was a transitional area with characteristics of both the *Typha latifolia–Carex lacustris* community and the *Chamaedaphne calyculata* community (Figure 1). At one time, this area may have been entirely ericaceous scrub. The construction of the recreation area and the apparent dredging and filling of the adjacent wetland (Anonymous 1974, 1975) may have altered the hydrology of this portion of the peatland. This disturbance could have altered the wetland enough to allow prolific *Typha* populations to invade and become established in the former ericaceous scrub community.

Lythrum salicaria was also found in the *Typha latifolia–Carex lacustris* community. *Lythrum* was limited to the southwestern portions of the peatland adjacent to the recreation area and the access road to the Moultonborough Highway Department. Due to its vigorous growth, an expansion of the *Lythrum* population may have a competitive impact on the distribution of other neighboring species.

7. *Nemopanthus mucronatus–Calamagrostis canadensis* (lagg) Community

The *Nemopanthus mucronatus–Calamagrostis canadensis* community surrounded the outermost perimeter of the peatland and immediately bordered the upland. The lagg (moat) represents a shift in substrate from peat to more mineral-rich, mucky soils. This transitional area between the peatland proper and the upland tends to be heavily shaded, collects leaf litter, and experiences seasonal variation in wetness (Crum 1988; Gore 1983). Higher concentrations of dissolved oxygen and minerals are present within lagg substrates. These subsidies support a flora characteristic of more nutrient-rich wetland environments such as marshes or swamps (Crum 1988; McQueen 1990).

The variable habitat conditions along the periphery of the peatland were reflected in the variety of vegetation patterns within the lagg. At the western edge of the peatland (Figure 1), the lagg contained standing water in which submersed species grew (e.g., *Potamogeton pusillus* and *Utricularia vulgaris*) as well as emergent species including *Sparganium americanum* and *Calla palustris*. In 1993, the eastern lagg abutting the gravel pit did not have standing water, but formed a swath of semi-liquid black muck. The herbaceous cover of this area was similar to the *Eriophorum* and *Carex* lagg phases described for Spruce Hole Bog (Miller 1996).

The northern, western, and southern lagg areas were dominated by shrubs including *Ilex verticillata*, *Nemopanthus mucronatus*, *Vaccinium corymbosum*, *V. myrtilloides*, and *Viburnum nudum*. *Alnus incana*, a species found frequently in the laggs of lakefill peatlands (Crum 1988) also was abundant. The lagg community at Mud Pond shared much of its flora with the Cinnamon Fern–Highbush Blueberry Thicket community described by Damman and French (1987). At Pequawket Bog, the lagg community was dominated by tall shrubs (> 1.5 m), especially *Acer rubrum*, *V. corymbosum*, and *Lyonia ligustrina*. Other characteristic species of this zone included *Alnus incana*, *Aronia melanocarpa*, *I. verticillata*, *N. mucronatus*, and *Rhododendron canadense* (Fahey and Crow 1995). The lagg community at Pequawket Bog shared similarities with both Heath Pond Bog (Fahey 1993) and Hillsborough Bog (Dunlop 1987).

At Mud Pond, open lagg areas not shaded by tall shrubs contained a diverse flora of herbaceous species including *Calamagrostis canadensis*, *Carex pseudocyperus*, *Scirpus cyperinus*, *Cicuta bulbifera*, *Epilobium leptophyllum*, *Lycopus uniflorus*, *Scutellaria galericulata*, and *Solanum dulcamara*. At Rochester Heath Bog, peripheral areas of the basin had

similar fen-like components dominated by *Carex canescens*, *Calamagrostis canadensis*, *Dulichium arundinaceum*, and *Lysimachia terrestris* (Barrett 1966).

State of New Hampshire Endangered species. Two species categorized as Endangered in the state of New Hampshire were found in Mud Pond Peatland (*Arethusa bulbosa* and *Carex diandra*). The range of *Arethusa* extends from Newfoundland to Ontario and Minnesota. *Arethusa* is rare south to New Jersey and northern Indiana, and disjunct into the mountains of North Carolina (Crow and Hellquist 2000a). *Arethusa bulbosa* was frequent throughout the sedge fringe along the perimeter of Mud Pond. Occasionally *Arethusa* was observed on tussocks along the edge of Mud Pond Brook.

The New Hampshire Natural Heritage Inventory (DRED 2000) lists twenty-one sites for *Arethusa bulbosa*. Of these twenty-one sites, only nine have been observed since 1979 (DRED 2000). Mud Pond peatland represents the fifth location for *Arethusa* in Carroll County with the majority of other records scattered over southeastern New Hampshire, especially in Rockingham County (DRED 1997). *Arethusa* is classified as "critically imperiled" within New Hampshire (DRED 2000).

The population of *Arethusa bulbosa* at Mud Pond was thriving and probably ranks as one of the largest in the state. In the northeast, populations of *A. bulbosa* have been in decline as a result of habitat loss and unscrupulous collectors (Damman and French 1987). A potential threat to *Arethusa*, and all of the endangered and threatened species at Mud Pond, is loss or alteration of habitat due to either human- or beaver-instigated manipulations of the surface hydrology. Another potential concern is the expansion of a population of *Lythrum salicaria*. *Lythrum salicaria* could conceivably colonize the sedge fringe habitats along Mud Pond and exclude individuals of *A. bulbosa*.

Carex diandra was an occasional inhabitant of the sedge fringe and marsh communities where it was found growing along channels of open water. Fernald (1950) states that *C. diandra* is found in bogs, peaty swamps, and calcareous wetlands. *Carex diandra* is a circumboreal species with a range extending south to New Jersey, Pennsylvania, Maryland, Illinois, Nebraska, Colorado, and California (Crow and Hellquist 2000a). With the exception of the Mud Pond record which represents the southernmost station for *C. diandra* in New Hampshire, the remaining localities are in western Coos County (DRED 1997).

State of New Hampshire Threatened species. *Lysimachia thrysiflora* (Swamp or Tufted loosestrife) is a circumboreal species with a range that extends south to northern New Jersey, Ohio, Illinois, Missouri, Nebraska, northern Colorado, and northern California (Crow and Hellquist 2000b). *Lysimachia thrysiflora* was relatively uncommon at Mud Pond. The largest population occurred along Mud Pond Brook at the south-southwestern end of the peatland. *Lysimachia thrysiflora* grew on tussocks along the edge of the brook in an area dissected by beaver paths and was occasionally observed in the southwestern lagg. In addition to Mud Pond peatland, there are seven documented records of *L. thrysiflora* (DRED 2000). These records are largely concentrated in Rockingham and Strafford Counties, with one record in Coos County. The Mud Pond record represents the first locality for this species in Carroll County.

Preliminary classification of Mud Pond peatland. New Hampshire peatlands tend to be small kettlehole or basin peatlands ranging in size from 0.5 ha or less to approximately 100 ha (Johnson 1985). Sperduto (1997) has presented a tentative classification of New Hampshire peatlands that is based upon Damman and French (1987), describing peatlands with regard to landform characteristics, vegetation patterns, and florisitic composition. Most peatlands in New Hampshire are topogenous, limnogenous, or a combination of both types (Sperduto 1997). Topogenous peatlands are found within low-lying parts of the landscape and receive runoff from uplands that wash over or through mineral soils. The hydrology of these peatlands is usually maintained by the water table (Damman and French 1987). Limnogenous peatlands often contain areas with emergent marsh vegetation and are distinguished by lakes and nutrient-poor streams that circulate water and nutrients within the peatland (Damman and French 1987).

Sperduto (1997) recognized five peatland vegetation communities in New Hampshire. These five physiognomic types were forests, tall shrub thickets, dwarf-shrub peatlands, sedge lawns or graminoid fens, and moss carpets/mud bottoms. The floras of most New Hampshire peatlands are indicative of acidic (poor) fens or more intermediate (oligotrophic) fens that receive limited mineral subsidies (Sperduto 1997). Of the New Hampshire peatlands that have published floras, Mud Pond peatland in Moultonborough is the most species-rich (Table 1).

The unique topography, hydrology, and flora of Mud Pond peatland does not lend the basin to a single, convenient classification. The peatland basin is composed of several discrete areas that adhere to

Table 1. Approximate area and vascular species richness of New Hampshire peatlands with existing species inventories. Data compiled from [1]Fahey 1993, [2]Dunlop 1987, [3]Miller 1996, and [4]Barrett 1966. *Mean area of peatland mat estimated by calculating approximate area from U.S.G.S. Hillsboro Upper Village topographic map and Dunlop (1987, Figure 4). **Mean area estimated from 1944, 1953, and 1962 aerial photographs of the open peatland mat.

Site	Area	Species Richness
Mud Pond Peatland, Moultonborough, Carroll Co.	12.2 ha	124
Pequawket Bog, Ossipee[1], Carroll Co.	9.9 ha	109
Mud Pond Bog, Hillsborough[2], Hillsborough Co.	10.7 ha*	107
Heath Pond Bog, Ossipee[1], Carroll Co.	16.2 ha	70
Spruce Hole Bog, Durham[3], Strafford Co.	1.0 ha	37
Rochester Heath Bog, Rochester[4], Strafford Co.	6.9 ha**	29

various aspects of the classification systems of Damman and French (1987) and Sperduto (1997). For example, Mud Pond peatland has aspects of both a topogenous and limnogenous system. Topogenous characteristics include the location of the peatland within a basin, the fringe of vegetation around the pond, the narrow *Sphagnum* lawns, and the extensive grounded mat areas.

Despite the topogenous characteristics of the basin, the northern and southern mat areas along Mud Pond Brook have characteristics of limnogenous peatlands. The peatland mat around the open water of Mud Pond classifies the system as a pond border peatland since the pond has not been entirely covered by vegetation (Damman and French 1987). The presence of the extensive *Typha latifolia–Carex lacustris* community attests to the relative minerotrophy of waters flowing through the more limnogenous areas of the peatland (Crum 1988; Damman and French 1987). Limnogenous peatlands are also characterized by *Sphagnum* spp., *C. lasiocarpa*, *Chamaedaphne calyculata*, and *Myrica gale* (Damman and French 1987).

Based on its floristic composition and the presumed chemical conditions that the flora reflects, Mud Pond peatland most resembles a poor to intermediate (oligotrophic) fen as described by Vitt (2000). Particularly telling is the dominance of *Sphagnum* in the peatland and the presence of ericaceous vegetation throughout the peatland, as well as sedges along the pond margin (Vitt 2000). Many of the taxa present at Mud Pond are considered species indicative of oligiotrophic conditions in New Hampshire peatlands. These taxa include *Sphagnum* spp., *Arethusa bulbosa*, *Calamagrostis canadensis*, *Carex lasiocarpa*, *C. trisperma*, *Decodon verticillatus*, *Drosera intermedia*, *Eriophorum tenellum*, *Lyonia ligustrina*, *Myrica gale*, *Pogonia ophioglossoides*,

Rhododendron canadense, *Solidago uliginosa*, *Triadenum virginicum*, and *Vaccinium macrocarpon* (Sperduto 1997).

The relative minerotrophy of the Mud Pond peatland basin amidst the generally acidic conditions of the Winnipesaukee diorite bedrock may be influenced by the proximity of the peatland to Red Hill and its relatively alkaline geology. Ground water and runoff in contact with Red Hill syenite may percolate into the peatland basin through surface and subsurface hydrology and therefore could be a source of nutrient ions. An influx of nutrient-enriched groundwater may account for some of the fen-like characteristics of the peatland flora. Further investigations of local geology and hydrology, as well as quantitative ecological surveys will further elucidate the flora and vegetation patterns of Mud Pond peatland.

ACKNOWLEDGMENTS. This paper is a revision and augmentation of an Honors Senior Thesis written by the senior author for the University of New Hampshire Department of Plant Biology (1994). Financial support was provided by the University of New Hampshire Undergraduate Research Opportunities Program through an Undergraduate Research Opportunities Grant (1993). Dan Sperduto of the New Hampshire Natural Heritage Inventory provided generous access to information from the Natural Heritage Inventory regarding Endangered and Threatened plant species. The town of Moultonborough and the other landowners of Mud Pond peatland kindly permitted access to their property. D. J. Leopold and the anonymous reviewers provided helpful comments that improved the manuscript. This paper is Scientific Contribution Number 2127 from the New Hampshire Agricultural Experiment Station.

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APPENDIX

THE VASCULAR FLORA OF MUD POND PEATLAND

The abundance of each species was estimated using the following visual abundance index for the checklist of the vascular flora. Abundant: Dominant or codominant in at least one community; Frequent: Easily observed in one or more communities, but not dominant; Occasional: Widely distributed but generally easy to locate; Rare: Difficult to locate, limited to two or fewer localities within the peatland. The checklist cites the physiognomic name of the communities or a specific location where a species was most prevalent.

EQUISETOPHYTA (Horsetails)

EQUISETACEAE

Equisetum arvense L. – Rare; NW lagg.
Equisetum sylvaticum L. – Rare; NW lagg.

POLYPODIOPHYTA (Ferns)

DRYOPTERIDACEAE

Dryopteris cristata (L.) A. Gray – Rare; NW lagg.
Onoclea sensibilis L. – Rare; NW lagg.

OSMUNDACEAE

Osmunda cinnamomea L. – Frequent; sedge fringe, lagg.
Osmunda regalis L. – Occasional; sedge fringe, marsh.

THELYPTERIDACEAE

Thelypteris palustris Schott – Frequent; sedge fringe.

PINOPHYTA (Gymnosperms)

PINACEAE

Larix laricina (Du Roi) K. Koch – Occasional; ericaceous scrub.
Picea mariana (Mill.) Britton, Sterns & Poggenb. – Frequent; muskeg.
Pinus strobus L. – Rare; ericaceous scrub.

MAGNOLIOPHYTA (Angiosperms)

MAGNOLIOPSIDA (Dicotyledons)

ACERACEAE

Acer rubrum L. – Frequent; muskeg, marsh.

APIACEAE

Cicuta bulbifera L. – Rare; NW lagg.

ANACARDIACEAE

Toxicodendron vernix (L.) Kuntze – Frequent; sedge fringe, lagg.

AQUIFOLIACEAE

Ilex verticillata (L.) A. Gray – Frequent; lagg.
Nemopanthus mucronatus (L.) Trel. – Frequent; lagg.

ASCLEPIADACEAE

Asclepias incarnata L. – Occasional; sedge fringe.

ASTERACEAE

Aster umbellatus Mill. – Rare; W lagg.
Bidens cernua L. – Rare; W beaver lodge.
Bidens connata Muhl. *ex* Willd. – Rare; W lagg.
Erechtites hieraciifolia (L.) Raf. – Rare; W beaver lodge.
Solidago uliginosa Nutt. – Frequent; sedge fringe, marsh.

BALSAMINACEAE

Impatiens capensis Meerb. – Occasional; NW lagg, on W beaver lodge.

BETULACEAE

Alnus incana (L.) Moench subsp. *rugosa* (Du Roi) Clausen – Frequent; sedge fringe, lagg.
Betula populifolia Marshall – Frequent; muskeg, ericaceous scrub.

CAPRIFOLIACEAE

Viburnum cassinoides L. – Frequent; lagg.

CLUSIACEAE

Hypericum mutilum L. – Rare; W beaver lodge.
Triadenum virginicum (L.) Raf. – Abundant; sedge fringe, marsh.

DROSERACEAE

Drosera intermedia Hayne – Rare; Damp hollows on the *Sphagnum* lawn.
Drosera rotundifolia L. – Frequent; *Sphagnum* lawn.

ERICACEAE

Andromeda glaucophylla Link – Frequent; muskeg, ericaceous scrub.
Chamaedaphne calyculata (L.) Moench – Abundant; throughout peatland.
Gaylussacia baccata (Wangenh.) K. Koch – Abundant; muskeg.
Kalmia angustifolia L. – Frequent; muskeg, ericaceous scrub.
Kalmia polifolia Wangenh. – Occasional; muskeg, ericaceous scrub.
Lyonia ligustrina (L.) Alph. de Candolle – Frequent; marsh, lagg.
Rhododendron canadense (L.) Torr. – Occasional; ericaceous scrub.
Vaccinium corymbosum L. – Abundant; muskeg, ericaceous scrub.
Vaccinium macrocarpon Aiton – Frequent; sedge fringe, marsh.
Vaccinium myrtilloides Michx. – Occasional; muskeg, ericaceous scrub.
Vaccinium oxycoccos L. – Abundant; *Sphagnum* lawn, ericaceous scrub.

FABACEAE

Trifolium repens L. – Rare; a few plants on a beaver slide through a *Sphagnum* lawn at the NE end of Mud Pond. Introduced from Eurasia (Gleason and Cronquist 1991).

LAMIACEAE

Lycopus uniflorus Michx. – Occasional; marsh, lagg.
Scutellaria galericulata L. – Frequent; marsh, lagg.

LENTIBULARIACEAE

Utricularia gibba L. – Rare; exposed mud along Mud Pond.
Utricularia intermedia Hayne – Frequent; submersed in beaver channels throughout sedge fringe.
Utricularia vulgaris L. – Frequent; submersed in Mud Pond, occasional in open water of W lagg.

LYTHRACEAE

Decodon verticillatus (L.) Elliott – Occasional; transition area between *Sphagnum* lawn and muskeg.
Lythrum salicaria L. – Occasional; SW marsh. Introduced from Eurasia (Gleason and Cronquist 1991).

MYRICACEAE

Myrica gale L. – Abundant; sedge fringe, ericaceous scrub, marsh.

NYMPHAEACEAE

Nuphar variegata Durand – Abundant; Mud Pond.
Nymphaea odorata Aiton subsp. *odorata* – Abundant; Mud Pond.

ONAGRACEAE

Epilobium leptophyllum Raf. – Occasional; marsh, lagg.
Epilobium strictum Muhl. *ex* Spreng. – Occasional; marsh, lagg.

POLYGONACEAE

Polygonum amphibium L. – Rare; W beaver lodge.
Polygonum arifolium L. – Rare; W beaver lodge.
Polygonum punctatum Elliott – Occasional; sedge fringe along Mud Pond Brook, lagg.

PRIMULACEAE

Lysimachia terrestris (L.) Britton, Sterns & Poggenb. – Occasional; N–NE lagg.
Lysimachia thrysiflora L. – Rare; sedge fringe at mouth of Mud Pond Brook and along lagg. New Hampshire Threatened Species.

ROSACEAE

Aronia arbutifolia (L.) Elliott – Occasional; marsh.
Aronia melanocarpa (Michx.) Elliott – Frequent; muskeg, marsh.
Fragaria virginiana Duchesne – Rare; several plants on W beaver lodge.

Rosa palustris Marshall – Frequent; sedge fringe.
Rubus hispidus L. – Occasional; muskeg, marsh.
Rubus pubescens Raf. – Rare; NW lagg.
Spiraea latifolia (Aiton) Borkh. – Frequent; sedge fringe, marsh, lagg.
Spiraea tomentosa L. – Occasional; lagg.

RUBIACEAE

Galium trifidum L. – Frequent; lagg, sedge fringe bordering the mouth of Mud Pond Brook.

SALICACEAE

Salix discolor Muhl. – Occasional; NW marsh, lagg.
Salix pedicellaris Pursh – Occasional; NW lagg.

SARRACENIACEAE

Sarracenia purpurea L. – Frequent; muskeg, *Sphagnum* lawn. New Hampshire Species of Special Concern.

SCROPHULARIACEAE

Verbascum thapsus L. – Rare; single population of several plants on W beaver lodge. Introduced from Europe (Gleason and Cronquist 1991).

SOLANACEAE

Solanum dulcamara L. – Occasional; lagg. Introduced from Eurasia (Gleason and Cronquist 1991).

VIOLACEAE

Viola macloskeyi Lloyd subsp. *pallens* (Banks *ex* Ging.) M.S. Baker – Rare; sedge fringe along Mud Pond Brook, on tussocks in the marsh and lagg.

LILIOPSIDA (Monocotyledons)

ALISMATACEAE

Sagittaria latifolia Willd. – Frequent; sedge fringe, *Sphagnum* lawn.

ARACEAE

Arisaema triphyllum (L.) Schott – Rare; NW lagg.
Calla palustris L. – Frequent; lagg, animal paths in the ericaceous scrub.
Peltandra virginica (L.) Schott & Endl. – Frequent; sedge fringe.

CYPERACEAE

Carex brunnescens (Pers.) Poir. – Frequent; muskeg, marsh.
Carex diandra Shrank – Occasional; sedge fringe, marsh. New Hampshire Endangered Species.

Carex lacustris Willd. – Abundant; marsh.
Carex lasiocarpa Ehrh. – Abundant; sedge fringe, frequent in marsh.
Carex lurida Wahlenb. – Rare; W lagg.
Carex pseudocyperus L. – Frequent; marsh, lagg.
Carex scoparia Schkuhr – Rare; W lagg.
Carex stricta Lam. – Frequent; marsh, occasional in lagg.
Carex trisperma Dewey – Abundant; muskeg, occasional in ericaceous scrub.
Carex utriculata Boott – Frequent; lagg, occasional in ericaceous scrub.
Cladium mariscoides (Muhl.) Torr. – Frequent; sedge fringe.
Dulichium arundinaceum (L.) Britton – Rare; W lagg.
Eleocharis olivacea Torr. – Occasional; on exposed peat of marsh and along Mud Pond.
Eleocharis smallii Britton – Frequent; sedge fringe.
Eriophorum gracile W. D. J. Koch – Rare; W marsh.
Eriophorum tenellum Nutt. – Rare; muskeg, lagg.
Eriophorum vaginatum L. subsp. *spissum* (Fernald) Hultén – Abundant; muskeg.
Eriophorum virginicum L. – Abundant; muskeg.
Rhynchospora alba (L.) Vahl – Frequent; muskeg, sedge fringe.
Scirpus cyperinus (L.) Kunth – Rare; marsh along Mud Pond Brook.
Scirpus subterminalis Torr. – Occasional; submersed along Mud Pond shoreline.
Scirpus tabernaemontani C. C. Gmel. – Rare; S marsh near Mud Pond Brook.

ERIOCAULACEAE

Eriocaulon aquaticum (Hill) Druce – Rare; on exposed muck along Mud Pond and Mud Pond Brook.

IRIDACEAE

Iris versicolor L. – Frequent; in lagg, along animal paths in the ericaceous scrub.

JUNCACEAE

Juncus brevicaudatus (Engelm.) Fernald – Occasional; sedge fringe.
Juncus canadensis J. Gay – Occasional; lagg.
Juncus effusus L. – Occasional; lagg.
Juncus pelocarpus E. Meyer – Occasional; sedge fringe, exposed muddy areas in W marsh.

LEMNACEAE

Lemna minor L. – Occasional; floating in beaver channels in sedge fringe, also in channels around tussocks in the marsh.

ORCHIDACEAE

Arethusa bulbosa L. – Frequent; sedge fringe. New Hampshire Endangered Species.
Calopogon tuberosus (L.) Britton, Sterns & Poggenb. – Frequent; *Sphagnum* lawn. New Hampshire Species of Special Concern.
Platanthera blephariglottis (Willd.) Lindl. – Occasional; sedge fringe, muskeg. New Hampshire Species of Special Concern.

Pogonia ophioglossoides (L.) Ker Gawler – Frequent; sedge fringe. New Hampshire Species of Special Concern.

POACEAE

Agrostis hyemalis (Walter) Britton, Sterns & Poggenb. – Rare; along beaver channel in W sedge fringe.
Brachyelytrum erectum (Schreber) P. Beauv. – Rare; NW lagg.
Calamagrostis canadensis (Michx.) P. Beauv. – Abundant; lagg.
Glyceria canadenis (Michx.) Trin. – Occasional; lagg.
Leersia oryzoides (L.) Swartz – Occasional; lagg.

PONTEDERIACEAE

Pontederia cordata L. – Occasional; sedge fringe.

POTAMOGETONACEAE

Potamogeton amplifolius Tuckerman – Frequent; submersed in Mud Pond.
Potamogeton epihydrus Raf. – Rare; single population submersed near the culvert at the southern end of Mud Pond Brook.
Potamogeton natans L. – Frequent; submersed in Mud Pond.
Potamogeton pusillus L. subsp. *tenuissimus* (Mert. and W. D. J. Koch) R. R. Haynes and C. B. Hellquist – Occasional; submersed in open water of W lagg.

SPARGANIACEAE

Sparganium americanum Nutt. – Rare; W lagg.
Sparganium natans L. – Frequent; beaver channels of sedge fringe.

TYPHACEAE

Typha angustifolia L. – Occasional; N marsh.
Typha latifolia L. – Abundant; N and S marsh.